## Preliminary Research Proposal (COE) (FY05)

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| TITLE: | Estuarine habitat and juvenile salmon – Current and historic linkages in the lower Columbia River and estuary |
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## Project Summary

Estuaries are considered important for the rearing of juvenile salmon and represent an integral component of the continuum of habitats that salmon occupy for significant periods of time. Recent analyses imply that the temporal and spatial patterns of estuarine rearing by juvenile Chinook salmon may have been simplified substantially compared with those of a century ago and that these changes are likely the result of a variety of human disturbances both upstream and within the estuary (Bottom et al. 2001). If this and other scientific assessments are correct (e.g., ISG 2000), then reduced diversity of salmon life histories, including those dependent upon estuarine habitats, has diminished the resilience and productivity of salmon in the Columbia River Basin.

There is, however, a general lack of information concerning what habitat attributes, particularly in the tidal freshwater and oligohaline transition zones, are needed to sustain diverse life histories of juvenile salmon in the Columbia River estuary. Further, recent evidence supports the concern that flow in the Columbia River significantly affects the availability of estuarine habitats, that flow is much reduced compared with historic levels, and that seasonal flow patterns are much different now than a century ago. The long history of wetland loss in the Columbia River estuary coupled with change in flow patterns suggests that restoration of these habitats may benefit recovery of depressed salmon stocks. Yet no empirical studies of tidal wetland habitats have been conducted in the Columbia River estuary to assess their ecological functions or to establish their significance as rearing habitat for juvenile salmonids.

This proposal addresses specific information needs identified in our recent review of the effects of the Columbia River hydropower system on salmon habitat, particularly the recommendation to "monitor variations in life-history diversity, habitat use, and performance of juvenile salmon in the estuary" (Bottom et al. 2001). The ultimate goal of this research is *to define habitat protection and restoration priorities for the Columbia River estuary based on (a) the relationships between estuarine habitat conditions and the life-history diversity, abundance, and performance of juvenile salmon; and (b) the potential responses of salmonids to past and future habitat change.* Toward these ends, we propose (1) long-term monitoring to track variations in abundance and life histories of juvenile salmon in the Columbia River estuary and of the landscape features and physical factors associated with these patterns; (2) detailed evaluations of salmonid use of wetland habitats of various successional stages and of the factors that influence development of these habitats and salmonid performance within them; and (3) evaluation of historic changes in river flow, sediment input, and habitat conditions in the estuary and the implications for juvenile salmon.

Our approach combines three major research components: empirical studies to define contemporary salmon-habitat associations and life-histories, historic analyses of physical habitat changes in the estuary, and modeling tools to assess the response of juvenile salmon to these or other potential changes. If we develop empirical associations between habitat attributes (e.g., salinity, depth, channel morphology, vegetation type, prey resources, etc.) and salmon distribution and performance (e.g., presence, abundance, residence time, and growth) then we can predict responses of juvenile salmon to past or future physical change. This information is needed to establish criteria for restoring estuarine habitat.

During later years of this proposed study, we will use model-based operational tools to "monitor" physical change (natural and human-induced variability) in the estuary and its impact on the availability of critical salmon habitat. To accomplish this objective, we will use the CORIE numerical modeling system for the lower Columbia River and estuary, which is being independently developed and validated. In 2003, we began exploring the practical feasibility of the CORIE modeling system as a monitoring tool, with initial focus on the ability of models to optimize field observations in the estuary, Cathlamet Bay, and selected marshes.

This FY05 proposal outlines objectives and tasks that continue ongoing studies in the Columbia River estuary, which are now in their fourth year. Accomplishments to date include: (1) continuation of a monthly beach seine monitoring program at seven sites in the lower Columbia River and estuary; (2) continued monthly trapnet sampling at the shrub wetland site at Welch Island with exploratory sampling of other shrub wetlands at Wallace Island; (3) Distributional surveys of salmon and other fish species along the outer perimeter and inner channels of the emergent marshes at Russian Island and testing of mark-recapture techniques for estimating salmon residence times in selected Russian island channels; (4) continuous real-time physical monitoring at fixed stations in the Cathlamet Bay region to compliment similar data collected from a network of stations (CORIE) distributed throughout the lower estuary; (5) historical analysis of river tides and estimates of daily changes in shallow water habitat area from 1893-1998 for the reach between Skamakawa and Beaver; and (6) development of protocols for historic habitat reconstruction and habitat change analysis in a GIS, with application to selected reaches of the estuary.

## Background

Estuaries are the link between ocean feeding grounds and freshwater rearing habitats for anadromous salmon. Only recently have estuaries been recognized as potentially more important to adult and juvenile salmon than simply providing a physical migration corridor (Casillas 1999). However, the scientific information identifying the important elements of the estuarine ecosystem and how they function to facilitate salmon survival is sparse. Nevertheless, despite increased awareness of the importance of estuaries to salmon survival (Bradford 1995), research and management activities remain focused primarily on the freshwater phase of the salmon life cycle.

Information about salmon habitat requirements needed to evaluate potential effects of human modifications of the lower Columbia River and estuary is very limited. Most biological surveys in the Columbia River estuary have been conducted over short time intervals (a few years or less), involving a limited range of habitat types and site-specific locations. A variety of environmental studies have evaluated the effects of dredging and other development activities in the estuary. Many of these target sensitive benthic invertebrate assemblages but, with a few exceptions, provide little or no information about the linkages between invertebrate prey and fish predators or about the effects of anthropogenic changes on salmonid habitats and salmon growth or survival. Furthermore, fish surveys in the Columbia River estuary primarily have targeted mainstem and distributary channel margins, which are heavily used by larger yearling ("stream-type") salmon migrants, including hatchery fish, which tend to migrate rapidly through the estuary to the ocean. Most surveys in the lower Columbia river have ignored shallow wetlands, forested swamps, sloughs, and other backwaters that may be among the principal habitats for small subyearling ("ocean-type") salmon that often rear in estuaries for extended periods (Reimers 1973). A long-term monitoring and evaluation program is needed (1) to insure that there are no adverse effects of planned anthropogenic modification of the Columbia River (either upstream or downstream from the dams) on estuarine-rearing salmonids in critical shallow water habitats, and (2) to develop criteria and a process for selecting, designing, and evaluating restoration projects based on their potential benefits to salmon rearing habitats and life-history diversity.

Research indicates that shallow, low-velocity estuarine habitats are particularly productive rearing areas for a variety of Pacific salmon species and life-history types (e.g., Levy and Northcote 1982, Levy et al. 1979). Life-history diversity within and among salmon species is reflected in varying times and sizes of entry to the estuary, periods of estuarine residence, habitat and microhabitat distribution, diet, and growth rates. In river-dominated systems like the Fraser and Columbia River estuaries, emergent and forested wetlands and their networks of shallow, dendritic channels and backwater sloughs offer refugia for small juvenile salmon from the strong current velocities of main river channels. Of particular concern for Columbia River salmon are the extensive tidal freshwater and oligohaline wetlands that encompass a critical staging area and transition zone, particularly for small subyearling salmon when they first encounter and must acclimate to salt water. Cathlamet Bay is an example of this transition area. The off-channel habitat complex within these transition zones constitutes biologically sensitive areas where small changes in salinity distribution could have substantial effects on the salmon rearing capacity of the estuary.

Unfortunately, 62% and 77% percent, respectively, of the historic emergent and forested wetlands of the Columbia River estuary have been lost to diking and filling (Sherwood et al. 1990; Thomas 1983) and may have substantially decreased the capacity of the Columbia River estuary to rear salmon. Substantial wetland losses may also reduce population diversity in the basin by removing habitats needed to support those salmon species and stocks with subyearling life histories. Despite increased interest in restoring tidal wetlands in the Columbia River estuary, in part to improve conditions for all declining salmon stocks, the specific features of salmon habitats that need to be reestablished or that dredging or other management activities must protect remain poorly defined.

The importance of flow as a factor affecting the availability of habitats important to juvenile salmon is beginning to be appreciated. Recent evidence evaluating the effect of change in flow and bathymetry in the lower Columbia River and estuary show strong, correlations between river discharge and availability of juvenile salmon habitats. This correlation is often very distinct between modern and pre-development conditions in the Columbia River estuary, as well as among different sub-regions of the estuary (A. Baptista, Oregon Graduate Institute; pers. commun.). In addition, available evidence suggests that historic flow patterns through the Columbia River estuary differed markedly from present-day conditions. Total annual flows are significantly reduced, spring freshets occur earlier, and winter flows are higher while those in the summer are much lower relative to historic patterns (D. Jay, Oregon Graduate Institute; pers. commun.). Understanding the effects of flow and other physical factors on salmon rearing opportunities in the estuary is important to devise management strategies that will aid salmon recovery.

## Research Goal

This proposal addresses specific information needs identified in our recent review of the effects of the Columbia River hydropower system on salmon habitat, particularly the recommendation to "monitor variations in life-history diversity, habitat use, and performance of juvenile salmon in the estuary" (Bottom et al. 2001). The ultimate goal of this research is *to define habitat protection and restoration priorities for the Columbia River estuary by determining (a) the relationships between estuarine habitat conditions and the life-history diversity, abundance, and performance of juvenile salmon; and (b) the potential salmonid responses to past and future habitat change.* Toward these ends, we propose (1) long-term monitoring to track variations in abundance and life histories of juvenile salmon in the Columbia River estuary and of the landscape features and physical factors associated with these patterns; (2) detailed evaluations of salmonid use of wetland habitats of various successional stages and of the factors that influence development of these habitats and salmonid performance within them; and (3) evaluation of historic changes in river flow, sediment input, and habitat conditions in the estuary and the implications for juvenile salmon.

## Approach

This proposal addresses factors at two important scales that determine the qualities of essential fish habitat and the performance of salmon. At the landscape scale, the estuary-wide distribution of habitats coupled to salmon migration behaviors determines whether individuals can readily access available habitats. For example, many studies have shown that salmonid movements and habitat use within estuaries are size-related. Small Chinook and chum salmon subyearlings (fry) usually occupy shallow, nearshore habitats, including salt marshes, tidal creeks, and intertidal flats (Levy and Northcote 1982; Myers and Horton 1982; Simenstad et al. 1982; Levings et al. 1986). As subyearling salmon grow to fingerling and smolt stages, their distribution typically shifts toward deeper habitats farther from the shoreline (Healey 1982, 1991; Myers and Horton 1982). Landscape-scale monitoring is necessary to interpret whether the migratory pathways and distribution of juvenile salmon of various sizes and life histories affect their ability to access and benefit from available estuarine rearing habitats.

At a finer scale, juvenile salmon performance is determined by physical and biological conditions and ecological interactions within particular habitats. Local differences in prey availability, water temperature, and habitat complexity, for example, ultimately determine salmonid feeding success, growth rates, and survival during estuarine residency. The local conditions and interactions within a habitat, in turn, may also depend on the geographic location and position of each habitat along the estuarine tidal gradient. For example, similar types of habitat in different estuarine locations may function differently due to tidal and riverine influences on temperature and salinity ranges or the abundance and composition of prey resources. In this way, understanding of local habitat linkages to salmon also requires reference to the larger landscape features within which each habitat is embedded. This proposal combines monitoring of salmon abundance, life histories, and habitat use at a broad landscape scale with detailed assessment of the ecological interactions affecting salmon within a variety of wetland habitat types.

We propose to develop our understanding of how the estuary currently and historically benefited juvenile salmon by determining salmonid distributions (presence/absence and abundance) and performance in relation to specific habitat attributes. Regions of particular interest include shallow water areas either adjacent to peripheral forests and wetlands or centrally located in the river, dendritic and channel margins, and sloughs. We will also place salmon-habitat associations in a historical context by evaluating river discharges and sediment inputs into the estuary for the past 100 years and reconstructing past and present availability of salmon habitat through the lower Columbia River and estuary using GIS mapping. During later years of study we will use modelling tools to "monitor" physical changes in the estuary and their impact on availability of salmon rearing habitats.

## Objectives and Tasks

**Objective 1. Compare trends in abundance and life histories of juvenile salmon at a landscape scale on representative shallow water habitats between Puget Island and the Columbia River mouth.**

The importance of shallow water areas and habitats along the river margin to estuarine-rearing salmon, the long history of wetland loss in the Columbia River estuary, the sensitivity of the tidal freshwater and oligohaline transition zone to small changes in salinity, and the lack of empirical information about the specific attributes of shallow water habitats needed to support salmon lead us to propose an evaluation of salmon and habitat associations in the tidally influenced lower river and estuary of the Columbia River.

The use of particular estuarine habitats as salmonid rearing areas will depend on (1) the location of each habitat along the tidal gradient relative to the source areas from which various juvenile populations enter the estuary, and (2) any size-specific behaviors that dictate habitat use among salmon with different juvenile life histories. For example, in many estuaries, small subyearling (ocean-type) migrants are more likely to rear for extended periods in shallow marsh-channel habitats and slough systems than larger yearling migrants that move more rapidly through the estuary to the ocean. In the

Columbia River estuary, use of shallow water habitats may thus differ for fish of different size and migration behaviors.

We propose a landscape-scale monitoring effort to characterize broad patterns of estuarine rearing and migration by juvenile salmon throughout the year, with emphasis on nearshore and shallow habitats of the lower estuary (below Puget Island). Our initial focus will be to establish a series of long-term indicator sites for characterizing life-history diversity among juvenile salmon as they first enter the lower estuary and as they exit the river mouth. As funding and manpower permit, we may later expand on this design to incorporate a greater diversity of habitat conditions and to assess whether our initial design adequately depicts trends in the diversity of rearing behaviors across the estuarine landscape. For example, we may consider additional locations along the tidal gradient or habitats representing different degrees of exposure to tidal and river currents (e.g., protected backwater areas versus exposed habitats along the main channel corridor). As the monitoring program progresses, we will assess whether changes or expansion of the initial sampling design are warranted based on results presented at our annual project review to be held before each new spring sampling season.

**Task 1.1. Select sites and conduct preliminary sampling.**

In 2002, we established a monitoring design to evaluate broad patterns of fish composition, abundance, habitat use, and rearing histories for various shallow nearshore habitats where juvenile salmon enter and exit the lower estuary (Figure 1). Stations are concentrated (1) in the area of Tenasillahe Island, where juvenile migrants must first choose whether to remain near the main estuary channel or select lower-energy backwater environments that lead into Cathlamet Bay; and (2) habitats near the estuary mouth, where salmon life-history diversity and relative abundances offer an overall indicator of estuarine and watershed conditions based on year-to-year variations among outmigrating juveniles. In 2003, we identified a series of six additional survey sites to represent a variety of shallow water habitats and energy regimes in the saltwater transition zone of Cathlamet Bay, where fish size and physiological state may substantially affect habitat selection and salmonid performance (Figure 1). We also selected three additional sites above Puget Island to characterize fish assemblages from an upper oligohaline area, including two sites adjacent to the ship channel and a protected backwater site behind Wallace Island (Figure 1)[1].

Progress to date:

1. Seven monitoring sites in the lower Columbia River estuary have been selected, and monthly sampling by beach seine has continued since November 2001.
2. Nine additional beach-seining sites supported by other USACE funds were selected in 2003-04 and were sampled concurrently with the seven established monitoring sites during May, July, and August 2004 (see Task 1.2 below). These additional sites expanded the variety of habitat types and locations depicted by our landscape-scale monitoring.

Proposed for FY 2005:

1. Analysis of biological results to date, including results from additional sites added in 2004, will dictate whether future changes in the long-term monitoring design are warranted (see Task 1.2 below). For example, comparisons of life history and genetic results for salmon my indicate whether sufficient differences exist to justify continued sampling of the seven monitoring sites originally chosen or whether one or more of the new sites sampled in 2004 should be incorporated in the ongoing monitoring program to improve representation of habitat and life-history variation. The sampling design for our landscape-scale monitoring will be reviewed during the annual project meeting in January 2005.

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[1] Additional sampling along the Cathlamet Bay "transect" and in new sites above Puget Island are supported by other USACE funds and described in a separate 2003-04 Scope of Work entitled, "Columbia River Estuarine Habitat Use by Juvenile Salmon – Baseline to Assess Potential Columbia River Channel Improvement Project Impacts."

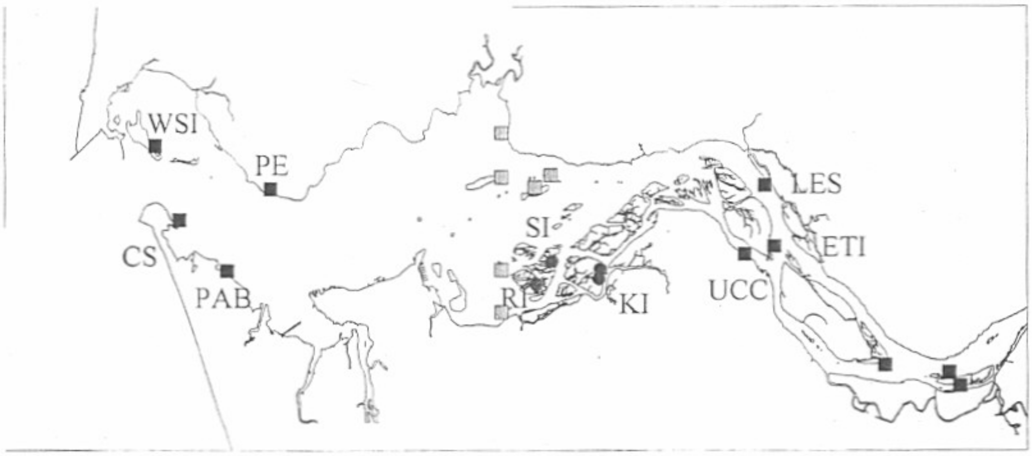


Figure 1: Beach seine sampling sites (black squares): WSI, West Sand Island. PE, Pt. Elice, CS, Clatsop Spit; PAB, Pt. Adams Beach; Trap net sample sites (red circles): SI, Seal Island; KI, Karlson Island, RI, Russian Island; LES, Lower Elochman Slough; ETI, East Tenasillahe Island;, UCC, Upper Clifton Channel. Additional beach-seine sites of the Cathlamet Bay "transect" (light blue squares) and the upper estuary zone between Puget Island and Wallace Island (dark blue squares) were also sampled during 2004. Sampling activities at these additional sites were supported by other USACE funds.

**Task 1.2. Monitor fish use at selected sites.**

We are sampling salmon at selected survey sites to characterize habitat use and ecology, including species and life history composition, relative abundance, size, and food resources. The sites are surveyed at monthly intervals or as otherwise dictated by tidal and seasonal conditions. Fish are sampled with a 50-m variable mesh (19.0-, 12.7-, and 9.5-mm) beach seine with knotless web in the bunt to reduce descaling. During deployment, one end of the seine is anchored on the beach while the other is towed by a skiff to enclose a ~2500 $m^2$ semicircular area. We sort the catch on site. For non-salmonids, we measure (nearest 1.0 mm) and released a representative sample (30 individuals) of each species. All other non-salmonids are counted and released. For salmonids, we retain a maximum of thirty individuals for genetic, scale and otolith (see Tasks 1.4 and 2.3 below), and stomach (Task 1.5) samples. In addition, we measured up to seventy individuals of each salmonid species prior to release. All salmon are examined for fin clips, coded wire tags, and PIT tags. Long-term monitoring (5 to 10 years, with a minimum of 4 years) is planned to establish monthly, seasonal, and yearly variations for the various species of juvenile salmon that utilize these habitats.

Progress to date:

1. Beach seine sampling commenced in November 2001 and is ongoing.
2. To date, we have sampled 6292 yearling and subyearling Chinook, 198 juvenile coho, and 1165 juvenile chum salmon. We retained 1859 Chinook for laboratory processing. We also collected an additional 802 fin clips for genetic analyses and 538 scales for scale analyses from Chinook that we released soon after capture.
3. During each year (2002 to date), juvenile Chinook were present in the lower Columbia River and/or estuary on every sampled occasion, with high abundances present May-July. Abundance of coho and chum were episodic in both time and location.
4. Fish assemblages also revealed spatio-temporal variation.

Proposed for FY 2005:

1. Continue monthly monitoring activities.
2. Complete analysis of 2002-2004 data to assess whether the existing monitoring design adequately depicts trends in salmon life-history and genetic diversity throughout the lower estuary. Revise sampling if necessary to more adequately reflect these trends or to eliminate unnecessary duplication of chosen sites.

**Task 1.3. Characterize physical factors.**

The physical variables that control and affect the availability of habitat in the lower river and estuary, such as flow velocity, salinity, and temperature, are being monitored. This project is benefiting from independently funded monitoring and modeling activities of the CORIE observation and forecasting system, which have a broader spatial scope, covering the full estuary and the near field of the plume. This task overlaps with and is detailed in Task 2.3 below.

**Task 1.4. Characterize juvenile salmon life history characteristics and habitat associations using scales and otoliths.**

Reimers (1973) presented evidence that distinctive scale circuli of juvenile salmonids correspond to particular life-history patterns. We will use scale analysis to assess the diversity of possible life-history patterns represented in samples collected from specific habitats in the lower Columbia River system. Habitats include our monitoring stations outlined in Tasks 1.1 and 2.1. Once validated, long-term scale collections could serve as a means to compare the performance of various life-history strategies based on their representation in juvenile and adult collections. We will also assess the use of scale circuli patterns to distinguish hatchery-reared fish from naturally spawned fish.

Otoliths are being collected from representative samples of salmonids and used to elucidate habitat use and growth. Chemical transects across sectioned otoliths will be conducted to track chemical changes in otolith composition. Since otoliths incorporate many chemical constituents in proportion to their environmental concentrations, the chemical transects can be used to reconstruct salmonid habitat use. In particular, analysis of age-specific strontium to calcium ratios have been related to migratory histories or environmental associations in several diadromous species (e.g. sockeye salmon, Rieman et al. 1994; striped bass, Secor and Piccoli 1996; eels, Tzeng and Tsai 1994; shad, Limburg 1995; and Arctic char, Radtke et al. 1996). Recent results from the Salmon River, Oregon and Skagit River, Washington showed that Chinook salmon captured from estuarine marsh habitats exhibited a dramatic increase in otolith strontium at some point after emergence (Volk, unpub. data). Combined with data from water samples, it seems clear that this obvious chemical signal corresponded with migrations of the juvenile fish from freshwater to estuarine habitats. These data will be collected in addition to daily increment widths, which are used to assess relative growth rates.

<u>Progress to date:</u>

1. For all months and sites for which salmon were successfully captured, a subsample of individuals has been retained for subsequent scale and otolith analyses.

2. A scale digitizing protocol has been established and scale samples from several sites have been digitized. These samples will be used for subsequent growth measurements and analyses of juvenile life histories based on pattern recognition.
3. A measuring protocol for scale circuli, scale radii, and features of interest has been established.
4. Scales have been removed and otoliths dissected from a subsample of all Chinook salmon retained from 2002-2003 trapnet and beach seine sites (n=500). In autumn 2004, additional scales and otoliths will be taken from frozen samples of Chinook salmon retained during the 2004 field season.
5. Approximately 50 scale samples have been digitized and measurements taken of scale growth between circuli, the proposed estuary check, and the scale edge.
6. Protocols for LA-ICPMS chemical analysis transects across salmon otoliths and for otolith increment counts and measures have been established based on concurrent work conducted in the Salmon, Skagit and Duwamish Rivers. We will apply these new protocols to chemical analysis of Columbia River otoliths. Results from all systems will be directly comparable.
7. Thin sections have been prepared from approximately 30 otoliths for subsequent chemical analysis.
8. "Checks" on scales of juvenile Chinook salmon have been identified as potential indicators of time of estuary entry.
9. Paired otolith and scale samples have been selected for comparing microchemical signatures using LA-ICPMS to validate whether the estuary check corresponds to the time of estuary entry.

Proposed for FY 2005:

1. Track strontium and other chemical signals in juvenile salmon otoliths to determine times of entry into estuarine habitats. First priority will be analysis of a subsample of 2002 otoliths from selected beach seine and trapnet stations. We will also examine the data for evidence of more specific fish-habitat associations within the estuary based on otolith microchemical signatures.

2. In tandem with the chemical transects, we will use daily increment records as a means to determine residence time between a chemical signal and the time of capture. Our primary objective will be to evaluate residence time in the estuary as evidenced by increased strontium, barium, and manganese abundance in the otoliths.
3. Daily increment widths will be used to assess relative growth rates of fish in different habitats or at different times in their life history based on the relationship between otolith growth and fish somatic growth (Volk et al. 1984; Neilson et al. 1985). We will compare otolith increment records with scale patterns to assess the relationship of scale circuli with time and compare the utility of each to predict relative growth histories of fish captured in different habitats.
4. Evaluate whether unique microchemical signatures can be detected on juvenile Chinook scales and can be used to independently validate life-history interpretations based on circuli patterns. If the scale technique proves successful, we will also compare microchemical signatures of scales with those of otolith samples from selected individuals to assess the utility of scales for predicting habitat associations based on microchemistry.
5. Compare historic and contemporary growth and life history patterns of juvenile Chinook salmon based on scale measurements reported by Rich (1920) and results of analyses from scales recently collected in the Columbia River Estuary. Scale measurements will include distance to each apparent estuary check, spacing of scale circuli, and distance to the scale edge.
6. Digitize and measure remaining subsamples of scales from Chinook salmon collected with the beach seine in 2003.
7. Compare growth patterns on scales of known hatchery (marked) and unmarked Chinook salmon.

**Task 1.5. Monitor trophic relationships of salmonid species and life history types in selected habitats throughout the lower Columbia River and estuary.**

We will examine spatial and temporal variation in juvenile salmonid diet associated with seven estuary sites and twelve months of the year. These results are needed to assess life-history specific associations with estuarine habitat. A preliminary assessment of salmonid stomach contents will allow us to establish a sensitive and practical long-term sampling design for both salmon and estuarine prey resources. Data processing will include (1) the percentage of empty stomachs, (2) the weight of stomach contents, and (3) categorization of diet composition (e.g. terrestrial insects, benthic invertebrates, plankton, fish). These data will be used to determine the extent salmon are feeding in the estuary, the prey types consumed, and seasonal or spatial variation of salmon diets within the lower Columbia River and estuary

Progress to date

1. Fish collected from the beach seine monitoring sites (Task 1.2) were stored at -80°C for diet analysis.
2. Five hundred and fifty-two Chinook stomachs were removed and preserved for analysis. This data set consists of 2002 and 2003 samples.
3. To date, 48 Chinook stomachs representing fish from two estuary sites in May 2002 and May 2003 have been processed.
4. Diet composition indicates subyearling Chinook are actively feeding in the estuary, although prey types vary according to whether fish are exposed to freshwater, marine, or mixed freshwater-marine prey assemblages.

Proposed for FY 2005:

1. Continue collection of diet samples from seven beach seine sites on a monthly basis.
2. Continue processing of stomach samples, including fish collected in 2004.
3. Communicate additional results to the estuary research team so that field sampling design or methodology can be refined, if necessary.

**Objective 2. Describe salmonid use and performance in selected emergent and forested wetlands and their relationship to local habitat features.**

Habitats that are important for rearing ocean-type juvenile salmon in other Pacific Coast estuaries have not been systematically sampled in the Columbia (Bottom et al.

2001). Shallow water wetlands, including both emergent marshes and shrub or forested wetlands have received little attention, even in the comprehensive CREDDP studies in the 1980s (Bottom et al. 1990). Our research approach requires that we accurately establish relevant empirical associations between habitat variables (both physical and biological) and juvenile salmon. If we develop empirical associations between habitat attributes (e.g., salinity, depth, channel morphology, vegetation type, prey resources, etc.) and salmon distribution and performance (e.g., presence, abundance, residence time, and growth) for various wetland types, then we can predict responses of juvenile salmon to past or future physical change. This information is needed to establish criteria for restoring estuarine habitats.

Understanding of salmon-habitat associations must also account for the dynamics of wetland succession which, over periods of decades or longer, shift the landscape of salmonid habitat opportunity across the entire estuary. Wetland habitats in the Columbia River estuary exhibit a natural sequence of developmental stages suggestive of vegetative and geomorphic succession, including low emergent marshes with complex dendritic channels; scrub/shrub wetlands of intermediate elevation and complexity; and mature forested wetlands, consisting of deep slough systems littered with large quantities of woody debris. The ecological functions of wetlands of various successional stages (including their use by salmon) may depend on their geographic position along the tidal gradient. Our surveys of wetland habitats are intended to contrast fish, prey resources, and habitat conditions among examples of the succession of vegetative and geomorphic types represented in the Columbia River estuary. We will then use GIS to infer changes in wetland rearing opportunities for salmon over the past century by comparing the historic and contemporary geography of wetland habitats in various successional stages (see Task 3.3).

Following the results of our first project review in January, we made several adjustments to the original sampling design to expand the variety of habitats and locations characterized by our wetland sampling. First, we discontinued sampling at the Seal Island emergent wetland, because patterns of salmonid use in 2002 and 2003 were similar to those observed at the Russian Island marsh nearby. This change allowed additional time to conduct a series of new fish distribution surveys along the outer margins and interior channel network at Russian Island near the established trapnet site (see task 2.1 below).

Secondly, we selected a new pair of sampling sites at Welch Island to examine effects of shrub-wetland location on salmonid use and benefits (Figure 2). Abundances of juvenile salmon have been consistently low at the Karlson Island shrub and forested sites, a pattern that may or may not apply to other shrub/forested wetlands in the estuary, In 2004, we collected fish and prey assemblages at the Karlson Island and at the new Welch Island shrub sites to evaluate effects of wetland location on habitat function.

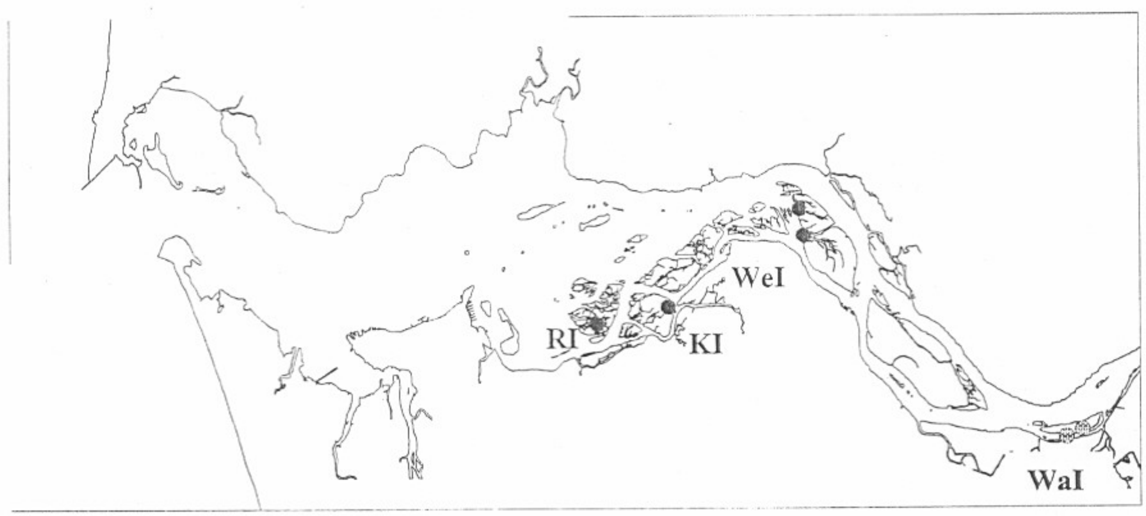


Figure 2. Revised trapnet locations sampled in 2004 (Sites sampled in 2002-03 are shown in Figure 1): Russian Island (RI), a pair of emergent marsh channels; Karlson Island (KI), a single shrub channel; Welch Island (WeI) two shrub channels. We also identified a pair of shrub sites at Wallace Island (WaI) that are proposed for exploratory sampling in 2005.

We will continue to expand the variety of habitat types and locations for our wetland sampling to compare effects of vegetative succession and geographic position on habitat functions for salmon. At the same time, we propose to institute new studies to examine the movements, residency, and growth of salmon within selected marsh habitats. We will begin by developing mark-recapture techniques to estimate salmon residency in emergent wetlands.

**Task 2.1. Sample fish at emergent and forested wetland sites in Cathlamet Bay**

We designed our initial wetland sampling in Cathlamet Bay (Figure 1) because it represents the largest concentration of shallow wetlands and spans the full oligohaline-brackish estuarine gradient available to juvenile salmon entering the Columbia River estuary. In 2004, we extended this design to include shrub wetlands distributed in the tidal fresh zone upriver at Welch Island. In 2005, we will continue to explore other wetland habitats upriver from Cathlamet Bay.

Progress to date:

1. We continued monthly monitoring of selected emergent and forested/shrub sites at Russian Island, Karlson Island, and Welch Island (Figure 2) from April through July or August, 2004. We also sampled the Russian Island site in February and March to monitor potential overwintering by yearling salmonids and document arrival of fry to the Cathlamet marshes in the early spring. For all sample dates and trapnet stations, we retained a subsample of salmonid species for dietary, genetic, and life-history analyses.
2. As fish abundances and water quality conditions allowed, we continued to conduct efficiency tests of our sampling gear by releasing groups of 10-30 marked (fin-clipped) salmon above each trapnet. The proportion of all marked Chinook recaptured when the tide drained at each channel site provided a measure of efficiency for adjusting absolute salmon catches at each site. Efficiency tests were discontinued later in the season to avoid handling stress and mortality during periods of increased water temperature.
3. The 2004 trapnet results showed consistent use of Cathlamet Bay marshes by subyearling Chinook. Chum salmon were relatively abundant for a short period, primarily in April. Total salmon abundances were generally higher in the emergent than in the forested or shrub wetlands, but direct density comparisons must wait until total channel area above each trapnet site has been estimated (see

Task 2.3.b). Densities of juvenile Chinook salmon were relatively high at the Welch Island sites during April and May.

4. We collected tissue samples to genotype a subset of Chinook salmon collected at all wetland trapnet sites. In 2003, most of the juvenile salmon collected within the marsh sites consisted of ocean-type Chinook from the lower Columbia River ESU with smaller numbers of fish from other ESUs. Analysis of selected 2004 samples is scheduled for the fall and winter.
5. We completed five surveys between April and September using a small (38 m) bag seine to compare salmon distribution within and outside the marsh-channel network near the established Russian Island trapnet site (Figure 2). We also collected benthic invertebrate samples at selected sites along the channel network. The objective of these surveys is (1) to assess whether fish species composition or salmon life history, food habitats, prey availability, or genetics respond to fine-scale habitat features of the island margins; and (2) to place local fish abundance patterns at the established trapnet site in a broader geographic context.
6. During the distributional surveys, we experimented with a Panjet® needleless injector to mark juvenile salmon with acrylic paint for potential residency studies at Russian Island. Initial marking tests were successful but more intensive sampling is necessary to recapture marked fish for the purpose of estimating residency periods.

<u>Proposed for FY 2005:</u>

1. In 2005, we will continue monthly trapnet sampling at the newly established Welch Island shrub site (Figure 2). Monthly sampling will occur March or April through August. We will continue to retain a subsample of all salmonid species from each date for dietary, genetic, and life history analyses.
2. We will discontinue monthly trapnet surveys at the Karlson Island shrub site and at the Russian Island emergent site to allow for additional sampling described below.
3. We will conduct exploratory surveys in 2005 to evaluate whether trapnet (or other alternative) gear can be used effectively to monitor fish use of other wetland

habitat types, including shrub wetlands at Wallace Island (Figure 2) and, if time allows, Scappoose Bay. Site suitability will depend on tidal amplitude, channel size, and accessibility of each site at all tide levels.

4. We will expand the 2004 bag-seine survey at Russian Island (Figure 3) to compare fish distribution across a wider array of marginal and interior-channel habitats of the marsh-island complex. This will include sampling at the 2004 sites (Figure 3) plus additional channel and island-margin sites on the opposite (northern) side of Russian Island. Five or six surveys will be scheduled between March and October to monitor distribution through the rearing season and assess potential movement of fish from the interior to the outer margins of the island complex.
5. We will initiate new studies to determine whether mark-recapture techniques can be used to estimate residency of juvenile salmon within selected Russian Island channels. These studies will involve intensive sampling (3 to 4 times per week) for a 4- to 6-week period during the spring. Initial tests will use batch-marking techniques (acrylic paint or freeze-branding) to determine whether individuals remain within a particular marsh-channel network for significant periods of time. From these preliminary results, we will determine whether PIT tags could be used effectively to measure individual growth rates and residence times of salmon in the Russian Island marsh.

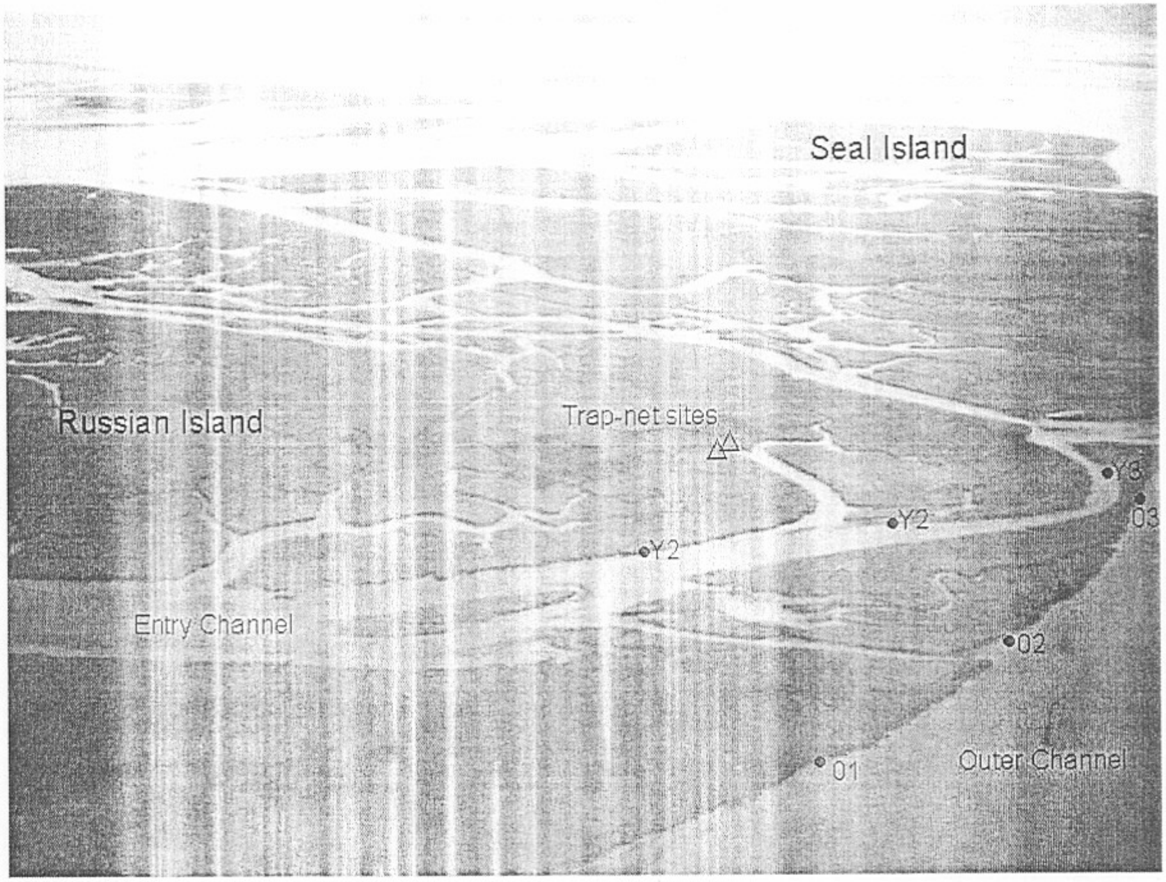


Figure 2. Preliminary sites chosen for beach seining at Russian Island. Proposed stations correspond with habitats of the outer margin (01 – 03) and the inner entry channel (Y1 – Y3) near our replicate trapnet sites established on a pair of secondary channels.

**Task 2.2. Monitor availability of invertebrate prey resources and food habits of juvenile salmonids and other selected fish predators.**

In order to assess the potential benefits of individuals occupying shallow wetland habitats, we are assessing diet composition from representative subsamples of juvenile salmon captured in emergent and scrub-shrub/forested wetlands. Correspondence (overlap) between the diets of salmon and available prey will allow us to examine trophic linkages between shallow water habitats and juvenile salmon. Our existing dataset suggests that insect fall-out traps and, to a lesser degree, benthic cores adequately characterize prey resources selected by subyearling, ocean-type juvenile Chinook salmon.

<u>Progress to date:</u>

1. In 2002, 2003 and 2004, we retained for dietary analysis a subsample of up to 10 individuals of each salmonid species found at each site for each survey date. We froze whole fish for subsequent stomach analysis because specimens are also required for corresponding life history (otolith) and parasitological examination. Moreover, because most fish in marsh samples were relatively small, we concluded that gastric lavage may not provide a suitable alternative to freezing whole fish for stomach samples. Before processing, the stomachs were removed from the frozen fish and placed in a buffered 10% formalin solution.
2. To assess the relative availability of prey organisms and their importance to salmonid diet and growth in wetland habitats, coincident with fish sampling we collected benthic organisms and fall-out insects at each tidal channel/slough. We collected benthic organisms in marsh and slough channels with a benthic core and insects on the marsh surface with fall-out traps using methods described by Gray et al. (2002). All prey samples were preserved for later analysis. Benthic invertebrates were preserved in a buffered 10% formalin solution, and the insects were preserved in 70% isopropanol.
3. We processed 2002 benthic invertebrate and fall-out trap samples for April and May and Chinook salmon stomachs for April and May 2002. The remaining fish, cores and traps from the Russian Island south channel 2002 will be processed, providing us with an adequate time series sample from within a specific channel.

4. Salmon numbers declined early in the 2003 rearing season, and we were unable to consistently collect stomach samples for all wetland sites throughout the spring-summer period. The most consistent samples available are for juvenile Chinook salmon. We have processed April, May and June 2003 stomachs and fall-out traps, as well as select benthic cores from April and May 2003. The remainder of benthic cores from April, May and June 2003 are currently being processed. Priorities were set for analyzing the remaining 2002 and 2003 prey-resource samples based on the best combination of dates for comparing prey resources to salmon diet (e.g., characterizing prey selectivity) and representing the food habitats of different life-history types or sizes of salmon. Processing and analyzing will continue throughout 2004.

5. The initial results from the insect fall-out trap collections show marked similarity among the four emergent channels (RuI-N, RuI-S, SI-N, SI-S) in both abundance and composition of insects in April, May, and June 2003, and all are drastically different from the two Karlson Island Channels (KI-F, KI-Sh). The Karlson Island channels have significantly lower abundances of insects, although no significant difference is detected in diversity. The dominant insect found in all of the emergent marsh insect traps was a dipeteran "midge" (Chironomidae). We have also surveyed and described the complex, diverse vegetation assemblages at our insect fall-out trap sites on each of the three wetland islands (Russian, Seal, and Karlson).

6. Initial results from the stomach content analyses indicate a higher relative consumption rate (measured by % IFI) for fish within the emergent marsh sites when compared to fish of the same size range in KI-F. KI-Sh was left out of this analysis due to the absence of fish in April and a lack of weight data in May, 2003, resulting in a very low sample size. All sub-yearling fish were placed into one of three size categories (40-59mm, 60-79mm, 80-106mm) in order to detect any differences in diet composition as the size of fish increased. A within-habitat shift in diet composition does occur as size of fish increases from small dipteran

insects (mainly chironomids) to a larger more diverse group of insects (including larger dipterans, neuropterans and trichopterans). From the results found in previous studies of juvenile Chinook salmon in the Columbia River estuary, it was expected that the benthic/epibenthic, tube-dwelling amphipod, *Corophium* spp., would be a dominant prey item in the larger fish diets. The lack of *Corophium* as a major diet component could possibly be explained by the lack of *Corophium* habitat in the intertidal, shallow water habitats that were included in this study. However, immediately outside of these channel areas, in the main channels, the sandy substrate is covered with *Corophium* tubes. Sampling of fish and invertebrates in these distributary channels began in 2004 at Russian Island.

Proposed for FY 2005:

1. The (Univ. Washington) M.S. thesis by Mary Austill Lott, addressing the differences in juvenile Chinook foraging and prey resource availability among emergent marsh, scrub-shrub and forested wetlands in the estuary, will be completed in December 2004. A manuscript for publication in peer-reviewed scientific journal will be submitted at that time.
2. In 2005, we will maintain collections of juvenile salmon stomachs and invertebrate prey during monthly fish surveys (March – August) at the Welch Island scrub-shrub site and for at least one month during the period peak salmonid densities in the spring (to evaluate interannual variability) at the Russian Island emergent-marsh site. We will also collect stomach and invertebrate benthic (core) prey samples during the peak period of catches during the distributional (bag seine) surveys around Russian Island. If fish are available from preliminary sampling of shallow water wetlands at Wallace Island, we will retain subsamples for diet analysis from these new habitats.
3. We will continue laboratory processing of stomach, insect, and invertebrate samples that were collected in 2004.

**Task 2.3. Characterize physical factors**

We are monitoring the physical attributes within selected estuarine and oligohaline habitats, including temperature, salinity, tide level, and other features. The characterization and interpretation of physical factors will include: (1) monitoring the physical attributes in Cathlamet Bay, (2) monitoring the physical attributes of beach seine sites and of channels located within selected marsh habitats, (3) estimation of physically-based habitat opportunity indicators, and (4) use of modeling as a monitoring tool (2003 and beyond). Each of these subtasks is discussed below.

**Subtask 2.3.a. Monitor physical attributes in the estuary**

A sub-network of the real-time CORIE field stations (Figure 4) was installed and has been collecting continuous measurements of water level (through pressure), salinity (through conductivity; except Woody and Tenasillahe), and temperature from sensors installed at one level in the water column. These stations and their base sensors will be maintained in a long-term basis.

Marsh Island has been instrumented with atmospheric sensors for direct measurement or estimation of air temperature, relative humidity, barometric pressure, wind (speed, direction and gust), solar radiation, long-wave radiation, latent heat and sensible heat. Observations of atmospheric parameters will be maintained continuously during the course of the estuary studies. Multi-level observations of temperature and one-level observations of turbidity observations at Marsh Island will start August 2004, but will be maintained long-term only if logistically feasible.

The CORIE web site (http://www.ccalmr.ogi.edu/CORIE) reports most of the data above (except some of the atmospheric parameters), both in real-time and in archival form.

Progress to date:

1. A large sub-network of sensors has been maintained to facilitate habitat characterization in the Cathlamet Bay region. Observations of conductivity/salinity, temperature, and pressure/water level have been conducted regularly at the following stations: Mott Basin, CBNC3 (now supported separately), Elliot Point, Marsh Island, Svensen Island, Woody Island (now

supported through this project), Tenasillahe Island and Grays Point (supported separately). An atmospheric station is also maintained at Marsh Island.

2. The calibration and installation of an optical backscatter sensor and an in-house built thermistor chain at Marsh Island is in progress; deployment is anticipated in August 2004.
3. Web-based display of unverified data is routinely conducted in real-time, with revised formats introduced in July 2004 (including selected atmospheric parameters). Verified archival data is available through 2003; 2004 data through June is being validated, and will be available August 2004.

Proposed for FY 2005:

1. Maintain physical monitoring of conductivity/salinity, temperature, and pressure at four stations (Mott Basin, Elliot Point, Marsh Island, Svensen Island) and of temperature and pressure at two stations (Woody Island and Tenasillahe Island). Stations CBNC3 and Grays Point will be maintained through separate funding.
2. Maintain monitoring of atmospheric parameters at Marsh Island, and improve associated data verification procedures.
3. Evaluate performance of a multi-level thermistor chain and a one-level optical backscatter sensor at Marsh Island.
4. Continue quality control of the data and expand and refine quality metrics and web products.

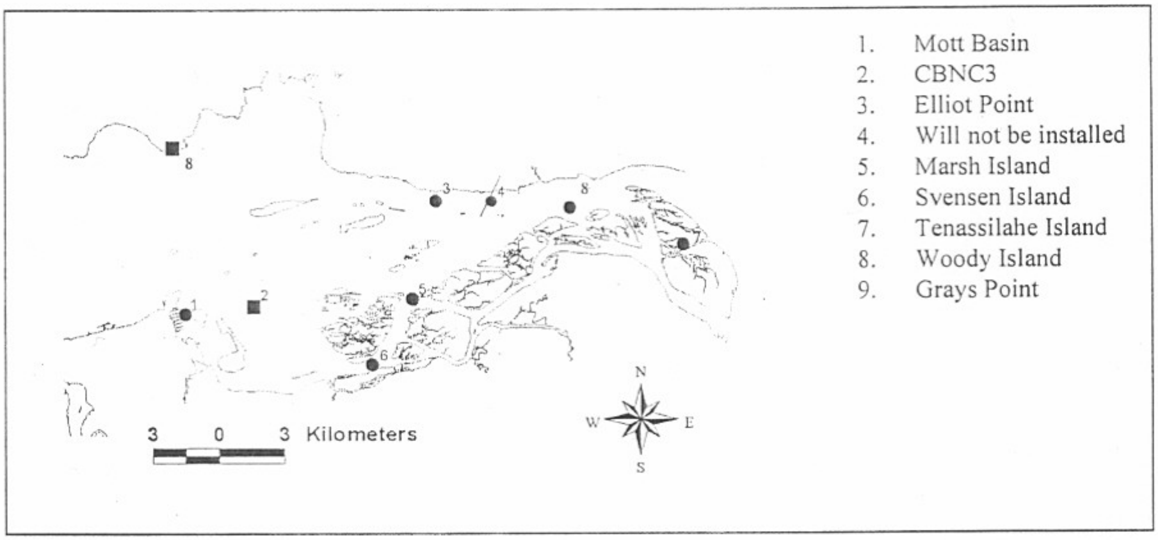


Figure 4: Six CORIE stations are currently maintained as a part of this project (circles). A station initially planned for Pillar Rock (station 4) was installed instead at Tenasillahe Island (station 7) to better support biological surveys. The two other CORIE stations in the map are supported through a different Corps of Engineers project (channel deepening monitoring)

**Subtask 2.3.b: Monitor physical attributes of beach seine sites and within selected marsh habitats.**

During regular beach seine operations, we profile the water column with a Sea Bird 19 plus CTD equipped with a Turner Designs SCUFA optical backscatterance sensor and a Wet Labs Wet Star fluorometer. Four casts are made perpendicular to shore in a transect extending from the beach seine site (2-5 m depth) out to the channel 250-300 m from shore. These data are used to evaluate vertical and horizontal gradients of salinity, temperature, chlorophyll a, and turbidity that may influence fish abundance. Data have been collected from November 2002 to the present.

In each region of emergent marsh and shrub/forested wetland sampling, and in some cases individual channels/sloughs, we will maintain small-scale continuous monitoring of physical conditions that will be potentially important determinants of juvenile salmon access and performance in these habitats. The continuous monitoring will be maintained as long as the field sampling program is repeated, including during the fall and winter between sampling seasons. Similar physical monitoring will be added to any new wetland sites selected for future biological studies.

Progress to date:

1. CTD transects have been made for all beach seine samples since November 2002.
2. We have observed large variations in patterns of physical gradients among sites and sample periods. Salinity gradients in the lower estuary could be exceptionally intense (at times exceeding 1 psu $m^{-1}$), while salt was not detected at the three upriver sites. Temperature and chlorophyll measurements followed seasonal patterns. Turbidity levels were quite variable, with strong vertical, horizontal, and between-site gradients apparent but without consistent pattern.
3. At the marsh sites, we continuously monitored water temperatures with data loggers located at several locations along the channel networks of one of the replicate emergent channels at Russian Island and at the shrub sloughs at Karlson Island and Welch Island.
4. To monitor water levels at each trapnet site, we deployed pressure gauges at the Russian Island, Karlson Island, and Welch Island sites in July 2004.
5. We completed high resolution GPS surveys of marsh and channel elevations relative to a NOAA tidal datum for each of the wetland study sites. These results will provide information to assess habitat opportunity for salmon under various tidal and river flow conditions (see Subtask 2.3.d). These data will also aid interpretations of vegetative composition (see Task 2.4) and the successional stage of each wetland site.
6. In late 2004, we will use CASI hyperspectral data and aerial photos to digitize the marsh channels at the Russian Island and Seal Island trapnet sites. These data will be used to calculate channel areas sampled above each trapnet and to compare other geomorphic indices (sinuosity, edge. etc.) potentially relevant to fish use.

Proposed for FY 2005:

1. We will continue CTD transects at all beach seine sites
2. We will continue monitoring temperatures within the marsh channel network of all trapnet sites and water levels at the entry to the marsh channels where pressure gauges have been deployed.

3. We will conduct seasonal CTD casts to characterize temperature, salinity, and dissolved oxygen variations within the channels/sloughs.

**Sub-task 2.3.c. Monitor sediment properties and sediment transport within selected marsh habitats (new sub-task).**

Sediment movement into and out of shallow water habitat areas is important to maintenance of the habitat, because it provides organic matter that fuels productivity, and because turbidity affects primary production and feeding behavior. This sub-task will monitor sediment characteristics and sediment movement into and out of shallow water environments.

Proposed for FY 2005

1. One channel will be instrumented during the 2005 spring freshet on a prototype basis. Three instruments will be deployed: a) an OBS to measure fine sediment concentration, b) a moored pressure gauge for tidal height, and c) an Acoustic Doppler Velocimeter (ADV) to measure near-bed sediment (coarse silt, aggregates and sand) concentration and transport, sediment settling velocity, local bedstress and local bed erosion/accretion. Using the OBS and ADV data together, fine sediment transport may be estimated at the instrument location.
2. Grab samples will be taken and analyzed for sediment size before and after the freshet, coincident with mooring deployment and removal. During instrument deployment and removal, water column properties will be assessed with a CTD, OBS and LISST-25X (concentration and mean size in two size ranges: 5- 63 microns and 63 -500 microns). Data will be processed and analyzed with the intent of establishing regular monitoring in 2006. Comparisons with the sediment in transport at Beaver will be made to see how material supplied to shallow water environments differs from that supplied to the estuary as a whole.

**Subtask 2.3.d. Estimation of physically-based habitat opportunity indicators**

BPA is currently funding a comprehensive study to develop physically-based habitat opportunity indicators.

Proposed for FY 2005:

1. In this project we will continue to provide quality-controlled observations (Section 2.3a), which are needed to validate model simulations and habitat-opportunity metrics generated through separate funding.

**Subtask 2.3.e. Use of modeling as a monitoring tool**

Modeling, in the sense of the CORIE continuous forecasts and long-term simulation databases, is potentially valuable in guiding strategies to optimize observation networks. In this part of the project, we use simulations generated though separate funding to periodically address the following questions related to the Cathlamet Bay monitoring network:

- Can CORIE simulations identify redundant observation stations, eventually leading to phasing out or relocating those stations?
- Can the CORIE forecasts help systematically prioritize the choice of location for any additional/alternative CORIE station in Cathlamet Bay?

Progress to date:

1. From annual climatologies of errors for CORIE simulation databases (1999-2003), we do not yet recommend replacing observations with simulations for any of the basic parameters (water levels, salinity and temperature). Refinements in bathymetry and grid discretization are being conducted through other funding that might change this recommendation at least for water levels in the next couple of years.

Proposed for FY 2005:

1. We will continue a low-level effort to evaluate the extent to which modeling can optimize the CORIE observation network in Cathlamet Bay.

**Task 2.4. Classify vegetation assemblage structure at each wetland site**

We are characterizing vegetation assemblage structure at each shallow water, wetland study site using the LCREP-generated classifications from remote sensing satellites (LANDSAT 7 ETM and panchromatic), and other sources (CASI hyperspectral) as available. These classifications and the delineation of discrete vegetation assemblages as habitat "polygons" are verified and systematically sampled by conventional vegetation composition and relative abundance analyses using percent cover and other (e.g., shoot density, canopy cover) measurements at each site.

Progress to date:

1. We have surveyed plant vegetation composition and frequency immediately adjacent to the insect fall-out traps at each wetland sampling site (Russian, Seal, and Karlson islands), providing "ground truth" for the LANDSAT TM and CASI hyperspectral data. The results also provide data to interpret the effects of vegetative composition on prey resource composition and availability at each wetland site.
2. Vegetative characterizations are also being used to interpret the broader (estuary-wide) patterns of wetland succession during the past century, including changes in community composition, marsh channel area, and channel geomorphology. This information, in turn, will allow us to apply our knowledge of contemporary fish-habitat associations to infer the quality and quantity of salmon rearing habitat available under historic wetland conditions (see Objective 3.3). This aspect of the project is a major element in the MS thesis of Ms. Crystal Elliot (Univ. Washington, Center Urban Hort.), which will be completed in August 2004.

Proposed for FY 2005:

1. With the addition of shallow water wetland study sites at Welch and Wallace islands to our established sampling design, we will conduct vegetative surveys at these sites to characterize assemblage structure and composition and continue to

incorporate these results into our analysis of successional changes relative to historic wetland conditions.

**Objective 3. Characterize historical changes in flow and sediment input to the Columbia River estuary and change in habitat availability throughout the lower river and estuary.**

Long-term changes in river flow, salinity, tidal, and sediment transport regimes of the Columbia River and its estuary have had a profound effect on Columbia River salmonids and their habitat. Human influences include the hydropower system (the largest single factor), irrigation withdrawal, navigational development, diking and filling, and changes in land use throughout the basin. These human alterations interact with each other and are difficult to separate from the influence of climate. Climate processes include a long-term increase in temperature, a decrease (relative to the $19^{th}$ Century) in flow, and fluctuations in flow related to the Pacific Decadal Oscillation (PDO) and the El Niño-Southern Oscillation (ENSO) cycle. Understanding how the river-flow, salinity, tidal, and sediment-supply regimes in the Columbia River system have evolved will provide critical information to develop appropriate management strategies, including the maintenance and restoration of shallow water habitats used by juvenile salmon.

**Task 3.1. Climate and human effects on river flow and sediment input.**

The goals of this task are to use recent geological history and available data to determine: 1) historical changes in the salinity and tidal regimes, 2) changes in water and sediment input to the system related to climate, human alteration and major geological events, and 3) the variations between sub-basins of climate and anthropogenic effects.

**Subtask 3.1.a. The interaction of tides, river flow, and shallow water habitat area.**

We will use historical data to analyze changes in the tidal regime caused by alteration in flow magnitude and seasonality. River flow controls juvenile salmonid habitat availability directly by altering river stage, and indirectly by influencing tidal range. There is also a daily power peaking cycle that propagates downriver to the vicinity of Beaver and markedly changes the character of the tide above Beaver, and affects the timing of high and low waters. These changes are relevant to salmonids for several reasons. First, it is important that Chum redds immediately below Bonneville Dam remain underwater during certain key periods, and water elevations in this portion of the river are a function of both dam operation and the oceanic tidal influence. Second, tidal range affects juvenile salmonid habitat location and availability during their migration through the lower river and estuary. Alterations of seasonality and strength of the annual river flow cycle and especially the changes in volume and timing of the spring freshet mean that the annual cycle of tidal range has changed since construction of the hydropower system. The net result is that habitat for juvenile salmonids has been displaced in time and space. Habitat availability reaches a maximum earlier in the season than historically and has been relegated to lower elevations (and decreased in extent) by the reduction in river stage in spring. Its character has changed both because of the displacement, and because tidal range during spring has increased.

Progress to date:

1. We improved the method for analysis of river tides devised by Jay and Flinchem (1997) and Flinchem and Jay (2000). We then analyzed the 1980-2001 Columbia River tidal height data set (about 50 station-years) to establish the response of tidal properties to river flow from the estuary to Bonneville Dam. This work is now published in *Journal of Geophysical Research* (Kukulka and Jay 2003a), and is described in detail in Tobias Kukulka's M.S. thesis (Kukulka 2002). In addition, a paper describing a method to hindcast river flow from tidal data is in press (Jay and Kukulka 2003).
2. We have established the response of river stage to flow throughout the lower-river and estimated, using a depth criterion, the shallow water habitat area (SWHA) available every day for the 1893-1998 period in the reach between Skamokawa and Beaver. Four SWHA scenarios were considered: (1) virgin flow-no dikes, (2) virgin flow-with dikes, (3) observed flow-no dikes, and (4) observed flow-with dikes). This work has now been published in *Journal of Geophysical Research* (Kukulka and Jay 2003b).

3. In conjunction with the BPA-funded estuary project, we are now analyzing historic tidal data from before 1980, focusing on two categories of data: 1) a spatially extensive 1940-42 data set collected when only one mainstem dam was operating (Bonneville), and 2) tidal data from Astoria from the 1850s to 1870s.
4. For most of the river, the 1940-42 data represents the best available description of pre-dam tidal behavior. Examination of the 1940-42 data suggests that power-peaking was not a common practice at that time, and there was little regulation of the mean flow. Thus, comparing the 1940-42 data with contemporary observations will help us determine the effects of both power peaking and flow regulation.
5. We have improved the spatial analysis method used in Kukulka and Jay (2003a,b). This involved analyzing spatial behavior before converting from real and imaginary parts to amplitude and phase for each tidal species. This step was taken to improve the statistical properties at the analysis at stations where only limited amounts of data were available.

<u>Proposed for FY 2005</u>

1. In the coming year, we will continue to analyze the influence of the pseudo-tide caused by the daily power peaking cycle at Bonneville Dam. Because the power-peaking cycle contains many non-tidal frequencies, the tidal analysis method employed to date does not fully describe this wave. A broader spectrum of frequencies will be analyzed in an attempt to more accurately capture its behavior.
2. The SWHA analyses will be continued. This will involve extending the area analyzed upriver toward Vancouver, separating human and climate influences on SWHA, and carrying out more detailed analyses of selected time periods of interest to the project. A paper, to be presented at an international meeting (Physics of Estuaries and Coastal Seas) in October 2004 will be submitted to a peer-reviewed journal.

**Subtask 3.1.b. Salinity intrusion and shallow water habitat.**

This subtask uses historical salinity, flow, and bathymetric data to understand changes in salinity patterns related to changes in river flow and bathymetry. Sporadic salinity data are available since 1933. These historic data will be digitized and analyzed in conjunction with river flow and tidal data to understand historical changes in salinity intrusion length as a function of river flow, tides and depth. Implications for shallow water habitat will be explored. We believe, for example, that the decreased flows during the spring freshet and deeper channels have together caused considerably greater salinity intrusion during the spring freshet, reducing shallow water habitat area. This work will be carried out beginning in year two.

Progress to date:

1. Selected data sets have been chosen for analysis and hypotheses have been derived.
2. We have determined that tidal fluctuations in salinity are quite helpful in diagnosing salinity intrusion dynamics. However, unlike tidal elevation, salinity has a base level (salinity =0) below which it cannot go. Therefore, analysis methods must be different than those used for tidal analysis. We have, therefore, developed an analysis method that treats the zero-salinity periods during the tidal cycle as gaps in the data, for purposes of determining tidal fluctuations in salinity.

Proposed for FY 2005:

1. This work will follow a path analogous to Subtask 3.1.a, but salinity data are sparse compared to the tidal height data. We expect by the end of 2005 to determine the dependence of salinity and stratification at selected stations on river flow and tidal range.
2. Understanding changes in the salinity distribution will require monitoring stratification in the estuary in future years. This task will be defined for future years, based on the results of data analyses.

**Subtask 3.1.c. Historical changes in quantity and quality of sediment input to the estuary.**

We will use historical accounts, the geological literature, and data collected by the USGS, Environment Canada, and the U.S. Army Corps of Engineers to understand changes in: (1) seasonality and amount of river flow, (2) the supply of fine and coarse material to the estuary, and (3) the quantity and quality of material supplied from selected sub-basins in relationship to climate change, catastrophic events, water withdrawal, and flow regulation. This task includes collaboration with the US Geological Survey in historical analyses.

Progress to date:

1. One element of hindcasting sediment supply to the estuary is to determine the historic flow at Beaver, which has been monitored only since 1991. We have implemented a routing algorithm from Orem (1968) to estimate a daily flow at Beaver for 1893-2001. We have also extended knowledge of spring freshet timing and volume back before the beginning of the daily record at The Dalles using historic records and newspaper accounts. These results have been published in part (Jay and Naik 2002). Also, a paper in press (Naik and Jay 2004) lays the basis for climate-change analyses for sediment by defining Columbia River virgin flow back to 1878.
2. Changes in volume and timing of sand transport and total load at Vancouver have been partitioned between climate change, flow regulation, and flow diversion. Rating curves for sand and fines transport have derived for the Willamette at Portland.
3. A presentation at an American Geophysical Union meeting (MacGregor et al. 2003) has examined historic changes in sediment transport rating curves; this work represents a collaboration with the US Geological Survey (USGS).

Proposed for FY 2005

1. We will continue work on estimation of a virgin flow for the Willamette River and for Beaver (1893-date) using USGS and Bureau of Reclamation data.

2. We will continue work on estimation of historic sediment transport (total load) at Beaver (1893-date). It may also be possible to partition this load between sand and fines. If Beaver virgin flow can be successfully estimated, then we can estimate virgin sediment transport at Beaver. Data archaeology and collaboration with USGS-Menlo Park will continue.
3. We will investigate the largest historic freshets since 1849, to determine the actual and virgin flow at Beaver. We believe that this analysis will show that most of the largest freshets in the system occur in the winter, though these are very brief compared to historic spring freshets.

**Task 3.2. Evaluate the amount and character of fine and coarse sediment inputs to the Columbia River and estuary.**

This task uses state-of-the-art optical methods to determine seasonal patterns in size distribution and concentration of sediment transported into the estuary. Coarse material plays a vital role in habitat maintenance and construction. Fine sediments contain organic matter that supports the estuarine food web, transports toxic materials, and causes turbidity that influences salmonid behavior and predation on salmonids. Much of the fine material in transport is actually in the form of aggregates, which are biologically active in the estuary. This task also includes collaboration with USGS with respect to sampling methods and monitoring at Beaver.

**Subtask 3.2.a. Monitor suspended sediment concentration and size at Beaver.**

The instrument to be used in this task is a <u>L</u>aser <u>I</u>n-<u>S</u>itu <u>S</u>cattering <u>T</u>ransmissometer (a LISST-FLOC manufactured by Sequoia Scientific). The LISST-FLOC uses scattering of laser light to divide particles between 10 and 1500 microns in diameter into 32 size classes. The LISST-FLOC is unique in that it measures not sand and fines, but aggregates. When deployed at Beaver (RM-53) over the entire year and supported with suitable calibration studies, this instrument will allow determination of seasonal patterns of suspended sediment input to the estuary.

<u>Progress to date:</u>

1. Field testing was carried out in both the Columbia (at Beaver) and in the Grand Canyon (to test the instrument in an environment with unaggregated large particles). Two conference presentations have been made (Jay et al. 2003, Chisholm et al 2003).
2. An exploratory field survey was carried out in June 2002 to investigate the cross-sectional distributions of flow, and of bed and water column (suspended) sediment at Beaver, and the tidal variations in water column properties.
3. The LISST-FLOC was deployed for almost 6 months at Beaver, from January to June 2004. Appropriate calibration data were collected, and analysis of the results is ongoing. We have concluded, however, that we want to mount the LISST in a horizontal (not vertical) position lower in the water column, despite greater logistical difficulties.
4. Suspended particulate matter is an important component of habitat, not just in the river, but also in the estuary and plume. Therefore, in June and July 2004, sampling was extended from Beaver to the Columbia River estuary and (with National Science Foundation support) to the Columbia River plume, to understand how particles are transformed as they move seaward. Another estuarine survey will be carried out later in 2004.

<u>Proposed for FY 2005:</u>

1. We will deploy the LISST-FLOC during a large part of the 2005 field season and winter 2004-2005. Sampling will be carried several times in the estuary and in the plume in spring and summer 2005 (with National Science Foundation support).
2. We will continue in 2005 to carry out 2-4-day, small-boat surveys to provide bed-form data (by side-scan sonar), bed sediment samples and information regarding the cross-sectional distribution of flow and suspended sediment. The concentration and size distribution data provided by the LISST-FLOC will be calibrated against bottle samples obtained during small-boat surveys.
3. We will begin the process of determining whether our LISST measurements can be combined with USGS data to provide actual suspended sediment transport estimates, partitioned by size (sand vs. fines). Several years of data, including

major winter and spring transport events will be required to develop such a protocol. This work will be coordinated with USGS monitoring at Beaver (see next subtask).

**Subtask 3.2.b. Coordination with the U.S. Geological Survey (USGS)**

There are three aspects to this coordination: (1) to coordinate our work with the flow gauging and water quality sampling routinely carried out by USGS (Portland District office), (2) we will work with the Grand Canyon Monitoring and Research Center (GCMRC), whose scientists are using LISST instrumentation to monitor sediment concentration and size in the Grand Canyon, and (3) we are working with USGS scientists at Menlo Park with respect to the issue of calibration of the new LISST-FLOC. USGS has experience calibrating previous versions of the LISST (cf. Gartner et al. 2001).

<u>Progress to Date</u>

1. We have carried out consultations with GCMRC personnel regarding their use of LISST instrumentation, and loaned them an instrument for test purposes. We now obtain Beaver acoustic backscatter data (which will assist in estimating suspended load) from USGS-Portland on a regular basis. We are exploring collaborations in the Willamette as well.
2. At no cost to the project, the LISST-25 we use to determine total concentration during vessel surveys was upgraded by its manufacturer (Sequioa Scientific) to a LISST-25X, which divides the total observed material into two categories: fines < 64Πand coarser material.

<u>Proposed for FY2005</u>

1. We expect to integrate our work at Beaver with USGS Portland District and continue exchange of data with USGS.
2. We will coordinate with USGS Menlo Park in a joint laboratory calibration of the LISST-FLOC. To this end we will assemble from parts a digital floc camera to provide an independent means of determining the size of particles used to test the LISST-FLOC.

**Task 3.3. Habitat change analysis**

We are generating historic habitat maps for the estuary from topographic surveys (T-sheets) conducted in the late 1800s at a scale of 1:10,000. These maps provide the historic template for habitat analysis by evaluating changes in the geographic distribution, amounts, and classes of estuarine and floodplain habitat available to juvenile salmonids from the estuary mouth (Rkm 0) to Rooster Rock (Rkm 206).

In FY 2002, a protocol was developed to reconstruct the historical habitat in a GIS to generate a geographically correct seamless coverage of the entire estuary at a resolution higher than existing map data. In addition, we devised a protocol for habitat change analysis, using historic floodplain and estuarine conditions to recently classified satellite imagery, with the aid of Columbia River Estuary Study Taskforce (CREST), Lower Columbia River Estuary Program (LCREP), and Earth Design Consultants, Inc, (EDC, Inc.). Select reaches in the estuary were chosen, based on geomorphologic characteristics, as pilot sites to demonstrate the historic habitat reconstruction and habitat change analysis. For these sites we generated historic habitat GIS maps and statistics describing results of the habitat change analysis.

The proposed tasks for FY 03 would have expanded the habitat reconstruction to the entire estuary and developed the historic habitat change analysis to regions not yet examined (e.g., above Puget Island). Work on these tasks was delayed due to FY 03 budget limitations and were among the tasks proposed for FY 04. Tasks for FY 2005 will be a continuation of the processes to complete the digitizing and classification of the T-sheets for the entire estuary. All data products resulting from these analyses will be accessible to CREST, LCREP, watershed councils, and local organizations.

<u>Progress to date</u>

1. Coordinated with LCREP, CREST, and EDC, Inc to derive a common habitat classification scheme between the historical and contemporary data sources
2. Established protocol for transferring historic habitat information from T-sheets to GIS, including georeferencing, edge matching, digitizing, and attributing.

3. Applied protocol for reconstructing historic habitat for representative reaches of each major geomorphic type in the estuary.
4. Performed habitat change analyses in select reaches using historical and contemporary data sources.
5. Recorded accuracy assessment, classification confidence, and error propagation.
6. Disseminated GIS map layers of historic habitat (late 1800s), habitat change detection, and error and confidence grids, in addition to spatial statistics.

Proposed for FY 2005:

1. Continue to implement protocol for habitat reconstruction on the remaining T-sheets to produce a complete GIS coverage of the historic estuarine habitats at a scale of 1:10,000.
2. Assess the quality and compatibility of the contemporary satellite imagery classification and habitat comparison, particularly in the upper estuary where habitat change analyses is lacking.
3. Adjust and enhance contemporary classification and positional accuracy of the satellite imagery.
4. Continue to coordinate with COE, NOAA Fisheries, LCREP, CREST, and other agencies to provide practical and accessible data products and results when needed.
5. If time permits, apply the habitat change analysis to additional reaches of the estuary.

## Fish Requirements for FY 2005

We plan to periodically sample fish primarily in the shallow water habitats of the lower Columbia River and estuary and will use the existing population of juvenile residents and outmigrant salmon. The sampling will focus on catch-and-release to determine presence and abundance in the various habitats sampled. A subset of the captured fish will be sacrificed to obtain measures of performance (growth, condition, food habits, etc.).

## Schedules

We are conducting the estuary study in multiple phases. The first year focused on identifying habitat sites for assessments and testing feasibility of sampling gear to capture juvenile salmon, selecting and positioning physical monitoring stations, beginning the historic reconstruction of flow and sediment input into the lower Columbia River, and estuary and habitat-change analysis. The second year included data collection, historic reconstruction of flow and sediment, and habitat-change analysis. We continued data collection in Years 3 and 4, developed analytical protocols for life-history analyses from scales and otoliths, and began the first laboratory analyses of selected fish and invertebrate samples. Field and laboratory activities will continue in Year 5, but some new wetland sampling activities are planned to survey salmon distribution in selected marginal and interior channel habitats of Russian Island, to test mark-recapture methods for estimating Chinook residence times in emergent marsh habitats, and to explore salmonid use of other wetland habitat types upstream of the Cathlamet Bay region. Plans for continued wetland surveys, including further mark-recapture studies and the potential for adapting PIT tag technology to monitor individual fish growth and behavior in marsh-channel habitats, will be re-examined after the 2005 field season. The need for any adjustment to the established landscape-scale monitoring design will be evaluated at our annual project review meeting in January 2005 based on an analysis of all beach seining results to date.

## Project Impacts, Facilities, and Equipment

Mooring sites and instrumentation will be needed to supplement the necessary physical monitoring of conditions in the Cathlamet Bay region. No impacts to listed ESU's are expected from the activities associated with this proposal.

## Project Personnel and Duties

1. Program Manager – Edmundo Casillas
2. NOAA Fisheries Project Leaders -- Daniel Bottom and Curtis Roegner
3. Monitoring salmon habitat use and abundance – Curtis Roegner and Susan Hinton
4. Identifying salmon-habitat associations – Daniel Bottom and Si Simenstad (University

of Washington)

5. Climatology and sediment inputs – David Jay and Thomas Chisholm (OGI School of Science & Engineering, Oregon Health & Science University)

6. Habitat change analysis – Jennifer Burke (Oregon Department of Fish and Wildlife)

7. Physical monitoring – Antonio Baptista (OGI School of Science & Engineering, Oregon Health & Science University)

8. Trophic relationships – Jen Zamon (NOAA Fisheries)

9. Otolith microstructure and scale analyses – Eric Volk (Washington Department of Fish and Wildlife) and Lance Campbell (Oregon State University)

## Technology Transfer

Technology transfer will be in the form of written and oral research reports. In January 2004, we organized the first annual estuary project review (1) to share preliminary findings with project cooperators and research staff, (2) to synthesize and integrate results from our diverse research activities, and (3) to prepare detailed sampling schedules for the upcoming field season. The second annual review meeting will be held in January 2005. A draft report will be provided to the COE by 15 December each year, with a final report provided by 15 March the following spring. Results will be published in appropriate scientific journals.

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